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DESCRIPTION

SPATIAL INFORMATION DETECTING DEVICE USING INTENSITY-MODULATED LIGHT

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TECHNICAL FILED

The present invention relates to a spatial information detecting device for receiving a light from a space into which an intensity-modulated light is being irradiated, and detecting information concerning the space such as a distance between an object in the space and the detecting device from the received light.

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BACKGROUND ART

A technique of detecting various information concerning a space by use of an intensity-modulated light has been known in the past. That is, the intensity-modulated light is irradiated from a light source into the space, and a light reflected from an object in the space is received by a photoelectric converter. According to the relationship between the intensity-modulated light and the received light, the spatial information can be obtained. In the present description, the spatial information includes a distance with object in the space, a change in the amount of received light brought by reflections on the object in the space, and so on. For example, the distance with the object can be determined from a phase difference between the intensity-modulated light and the received light. In general, this technique is called the time-of-flight method.

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For example, US patent No. 5,856,667 discloses apparatus and method using the time-of-flight method. According to the time-of-flight method, the light emitted from the light source is intensity-modulated by a required emission frequency, and the photoelectric converter detects the

intensity of received light plural times within a time period shorter than a modulation period that is the reciprocal of the emission frequency. When the intensity of the light emitted from the light source is modulated by a sine wave, the intensity of received light is detected by the photoelectric converter at a certain phase of the modulated light. For example, the intensity of received light is detected 4 times within the modulation period, and the phase difference is determined from the detected four intensities of received light.

When the light emitted from the light source is intensity-modulated, as shown by the curve "S1" of FIG. 31, and the modulated light reflected from the object in the space is received by the photoelectric converter, the intensity of received light changes, for example, as shown by the curve "S2" of FIG. 31. In this case, the four intensities (A_0' , A_1' , A_2' , A_3') of received light can be detected at 4 different phases (0° , 90° , 180° , 270°). However, in the present circumstances, it is impossible to detect the intensity of light received at just the moment of the each of the phases (0° , 90° , 180° , 270°). In the fact, each of the intensities of received light corresponds to the intensity of light received within a time width " T_w ", as shown in FIG. 31.

On the assumption that the phase difference " ψ " does not change within the modulation period, and there is no change in light extinction ratio (In FIG. 31, the light extinction ratio is not considered) within a time period from the time of emitting the light to the time of receiving the light, the relationship between the intensities (A_0' , A_1' , A_2' , A_3') of received light and the phase difference " ψ " can be represented by the following equation:

$$\psi = \arctan \{ (A_3' - A_1') / (A_0' - A_2') \}$$

Thus, the technique of determining the phase difference (ψ) according to the intensities (A_0' , A_1' , A_2' , A_3') of received light detected

within the modulation period is available as a distance measuring method. A maximum distance "L" [m] that is measurable by this distance measuring method is approximately a half of wavelength of the sine wave to be intensity-modulated. That is, when "c" designates speed [3.0×10^8 m/s] of light and "T" designates modulation period [s], the maximum distance "L" is represented by the equation: $L = c \cdot (T/2)$. Therefore, the modulation period "T" can be calculated by the equation: $T = 2L/c$. For example, when the maximum distance "L" is set to 3 m, the modulation period is 20 [ns] ($= 2 \times 3 / (3.0 \times 10^8)$).

In the above case, the intensity of received light must be detected every quarter wavelength of the modulation period. This means that the intensity of received light must be detected under about 1 [ns] of the time width "Tw" every several nanoseconds [ns]. Therefore, a switching element having high-speed response is needed. In addition, when a distortion of the waveform of the light received by the photoelectric converter occurs due to a distortion of the signal waveform for driving the light source or a temporal change in the amount of light incoming from outside into the space, it becomes difficult to accurately determine the phase difference " ψ " according to the intensities of received light (A0', A1', A2', A3'). As a result, it leads to a reduction in distance measuring accuracy.

SUMMARY OF THE INVENTION

Therefore, a concern of the present invention is to provide a spatial information detecting device using an intensity-modulated light, which has the capability of accurately detecting information about the space such as a distance between an object in the space and the device without using an expensive switching device having high-speed response.

That is, the spatial information detecting device of the present

invention comprises:

at least one photoelectric converter for receiving a light provided from a space into which a light intensity-modulated at a predetermined emission frequency is being irradiated, and generating an electrical output corresponding to an intensity of received light;

a local oscillator circuit for outputting a local oscillator signal having a local oscillator frequency different from the emission frequency;

a sensitivity controller for mixing the local oscillator signal with the electrical output to frequency convert the electrical output into a beat signal having a lower frequency than the emission frequency;

an integrator for performing integration of the beat signal at a predetermined timing; and

an analyzer for determining information about the space according to an output of the integrator.

According to the present invention, even when a distortion of waveform of the light received by the photoelectric converter occurs due to a distortion of signal waveform for driving the light source or a temporal change in the amount of light incoming from outside into the space, it has little influence on integrals of the beat signal used to determine the spatial information. Therefore, there is an advantage that the spatial information can be accurately detected, as compared with conventional detecting devices for determining the spatial information with use of the waveform.

In addition, since the spatial information is determined by use of the integration of the beat signal having a lower frequency than the emission frequency of the intensity-modulated light, it is possible to use a relatively cheap switching device at the light receiving side in place of an expensive switching device having high-speed response. For example, when measuring time to determine the spatial information, the time measurement is performed with respect to the beat signal having the lower

frequency than the emission frequency. Therefore, as compared with the case of measuring time without frequency conversion, it is possible to perform the time measurement with a relatively low degree of accuracy.

As a preferred embodiment of the present invention, the integrator
5 performs the integration of the beat signal with respect to a plurality of integration ranges, each of which is determined within a given phase interval of the beat signal, and the analyzer includes determining a phase difference between the light irradiated into the space and the light received by the photoelectric converter from resultant integrals of the plurality of
10 integration ranges. In this case, by using the phase difference between the light irradiated into the space and the light received by the photoelectric converter, it is possible to determine the spatial information such as a distance between an object in the space and the spatial information detecting device or a change in intensity of received light
15 caused by reflection on the object in the space. In addition, since the integrals determined from the plurality of integration ranges of the beat signal are converted into the phase difference, it is not needed to synchronize with the light emitting side. As a result, it is possible to determine the distance by use of a relatively simple device structure.

20 It is preferred that the sensitivity controller comprises a semiconductor switch provided between the photoelectric converter and the integrator. In this case, since the semiconductor switch receives and gives electric charges between the photoelectric converter and the integrator, it is possible to use the semiconductor switch for frequency
25 conversion in addition to selecting information for the integration.

As a further preferred embodiment of the present invention, the photoelectric converter generates, as the electrical output, amounts of electric charges corresponding to the intensity of received light. The integrator is provided with a charge storage for storing as signal charges

at least part of electric charges generated by the photoelectric converter, and a charge ejector for ejecting the electric charges from the charge storage in synchronization with the beat signal having a frequency difference between the emission frequency and the local oscillator frequency. The sensitivity controller has a function of modulating, at the local oscillator frequency, a ratio of amounts of electric charges migrating to the charge storage relative to the amounts of electric charges generated by the photoelectric converter. Since the sensitivity of the light receiving side is controlled by the local oscillator frequency to obtain the beat signal, it is possible to easily achieve the purpose of the present invention with use of, as the photoelectric converter, a light receiving element, of which the sensitivity can be adjusted by the signal of the local oscillator frequency.

It is also preferred that the charge storage stores the signal charges of a plurality of ranges, each of which is determined within a given phase interval of the beat signal, and the analyzer includes determining a phase difference between the light irradiated into the space and the light received by the photoelectric converter from the stored signal charges of the plurality of ranges. In this case, by using the phase difference between the light irradiated into the space and the light received by the photoelectric converter, it is possible to determine the spatial information such as a distance between an object in the space and the spatial information detecting device or a change in intensity of received light caused by reflection on the object in the space.

In addition, it is preferred that the sensitivity controller comprises a storage gate provided between the photoelectric converter and the charge storage to adjust amounts of electric charges migrating from the photoelectric converter to the charge storage, and/or a charge discarding unit for removing, as unnecessary charges, at least part of the electric

charges generated by the photoelectric converter. In this case, since amounts of electric charges discarded from the photoelectric converter is controlled to adjust the mounts of electric charges migrating from the photoelectric converter to the charge storage, it is possible to separately
5 control the timing of controlling the charge discarding unit and the timing of storing electric charges in the charge storage to perform the frequency conversion, and accordingly minimize amounts of noise components mixed into the signal charges. In addition, when the sensitivity controller has both of the storage gate and the charge discarding unit, it is possible
10 to control discarding the unnecessary charges, while simultaneously performing the frequency conversion and storing the signal charges.

As another preferred embodiment of the present invention, the spatial information detecting device has a plurality of photoelectric converters. The charge storage of the integrator is a CCD (charge-
15 coupled device) having a region of storing, as signal charges, at least part of electric charges generated by each of the photoelectric converters at a region corresponding to a gate electrode provided every photoelectric converter. The charge ejector is a CCD for transferring the signal charges from the charge storage to outside. The charge discarding unit
20 is formed with an overflow drain for discarding at least part of electric charges generated by each of the photoelectric converters in a batch manner according to an external signal. The photoelectric converters, the charge storage, the charge ejector, and the charge discarding unit are mounted on a single semiconductor substrate to obtain an image sensor.
25 The sensitivity controller is at least one of the gate electrode and the charge discarding unit. In this case, as the image sensor for the spatial information detecting device of the present invention, an interline transfer CCD image sensor having an overflow drain or a frame transfer CCD image sensor having an overflow drain can be used. Therefore, it is

possible to readily achieve the purpose of the present invention without using special circuit designs or devices.

5 It is further preferred that the image sensor has a light shielding film on regions of storing electric charges and not relating to the generation of electric charges. It is possible to prevent the generation of noise components at the photoelectric converters and improve the S/N ratio.

10 It is also preferred that the sensitivity controller is at least one of the gate electrode and the charge discarding unit, and a voltage applied to the gate electrode and/or an external signal to be given to the charge discarding unit is modulated by the local oscillator frequency. In this case, since the overflow drain of the CCD image sensor is modulated by the local oscillator frequency, it is possible to perform the frequency conversion independently with the timing of storing the signal charges in the charge storage, and accordingly minimize the amounts of noise components mixed into the signal charges. In addition, when the sensitivity controller is composed of the gate electrode and the charge discarding unit, it is possible to control discarding the unnecessary charges, while simultaneously performing the frequency conversion and storing the signal charges.

20 As still another preferred embodiment of the present invention, the spatial information detecting device has a plurality of photoelectric converters, and a set of photoelectric converters is selected from the plurality of photoelectric converters to define one pixel. A plurality of sensitivity controllers corresponding to the photoelectric converters of the set are modulated by local oscillator signals having a same local oscillator frequency and different phases from each other. The charge ejector simultaneously outputs the signal charges corresponding to the different phases of the beat signal obtained by the photoelectric converters of the

set. In this case, since the signal charges corresponding to the different phases of the beat signal are simultaneously obtained, it is possible to more efficiently detect the spatial information.

Moreover, it is preferred that the analyzer includes determining a phase difference between the light irradiated into the space and the light received by the photoelectric converter from the signal charges corresponding to the different phases of the beat signal. Since the signal charges stored in the plurality of ranges of the beat signal are converted into the phase difference, it is not needed to synchronize with the light emitting side. Accordingly it is possible to determine the spatial information by use of a relatively simple device structure.

In addition, it is preferred that the analyzer includes converting the phase difference into distance information. In this case, a distance measuring device can be provided as the spatial information detecting device.

These and still other objects and advantages of the present invention will become more apparent from the best mode for carrying out the invention explained below, referring to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a distance measuring device according to a first embodiment of the invention;

FIG. 2 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

FIG. 3 is a schematic diagram of an image sensor for a distance measuring device according to a second embodiment of the invention;

FIG. 4 is a schematic diagram of another image sensor for the distance measuring device according to the second embodiment.

FIG. 5 is a plan view of an image sensor of a distance measuring device

according to a third embodiment of the invention;

FIG. 6 is an exploded perspective view of a relevant portion of the image sensor.

FIG. 7 is a cross-sectional view cut along the line A-A of FIG. 6 or 11;

5 FIG. 8 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

FIGS. 9A to 9C are explanatory diagrams illustrating the principle of operation of the distance measuring device;

10 FIGS. 10A and 10B are explanatory diagrams illustrating the principle of operation of a distance measuring device according to a fourth embodiment of the invention;

FIG. 11 is a plan view of an image sensor for a distance measuring device according to a fifth embodiment of the invention;

15 FIG. 12 is an exploded perspective view of a relevant portion of the image sensor.

FIG. 13 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

FIGS. 14A to 14C are explanatory diagrams illustrating the principle of operation of the distance measuring device;

20 FIG. 15 is a plan view of an image sensor for a distance measuring device according to a sixth embodiment of the invention;

FIG. 16 is a perspective view of a relevant portion of the image sensor.

FIG. 17 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

25 FIG. 18 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

FIGS. 19A to 19C are explanatory diagram illustrating the principle of operation of the distance measuring device;

FIG. 20 is a plan view of an image sensor for a distance measuring device

according to a seventh embodiment;

FIG. 21 is a perspective view of a relevant portion of the image sensor.

FIG. 22 is an explanatory diagram illustrating the principle of operation of the distance measuring device;

5 FIGS. 23A to 23C are explanatory diagram illustrating the principle of operation of the distance measuring device;

FIGS. 24A and 24B are explanatory diagram illustrating the principle of operation of a distance measuring device according to an eighth embodiment of the invention;

10 FIGS. 25A and 25B are explanatory diagram illustrating the principle of operation of a distance measuring device according to a ninth embodiment of the invention;

FIGS. 26A and 26B are explanatory diagram illustrating the principle of operation of a distance measuring device according to a tenth
15 embodiment of the invention;

FIG. 27 is a perspective view of a distance measuring device according to an eleventh embodiment of the invention;

FIGS. 28A and 28B are explanatory diagram illustrating the principle of operation of the distance measuring device;

20 FIG. 29 is a plan view of an image sensor for a distance measuring device according to a twelfth embodiment of the invention;

FIG. 30 is a plan view of an image sensor for the distance measuring device according to a modification of the sixth embodiment; and

25 FIG. 31 is an explanatory diagram illustrating the principle of operation of a conventional distance measuring device.

BEST MODE FOR CARRYING OUT THE INVENTION

In preferred embodiments described below, as an example of a spatial information detecting device of the present invention, distance

measuring devices using a phase difference between an intensity-modulated light and a received light by a photoelectric converter are explained in detail. However, needless to say, the present invention is not limited to those distance measuring devices. It should be interpreted
5 that the technical idea of the present invention is available to any devices required to determine the above-described phase difference.

(First Embodiment)

As shown in FIG. 1, the distance measuring device of this embodiment has a light source 1 for emitting a light into a required space.

10 The light emitted from the light source is intensity-modulated at a predetermined emission frequency by an emission controller 2. As the light source 1, for example, it is possible to use an array of light emitting diodes (LED) or a combination of a semiconductor laser and a divergent lens. As an example, the emission controller 2 intensity-modulates the
15 light emitted from the light source 1 by a sine wave of 20 MHz.

In addition, the distance measuring device has a plurality of photoelectric converters 3 for receiving a light provided from the space through a lens 4. Each of the photoelectric converters 3 generates an electric output corresponding to an intensity of received light. In other
20 words, the photoelectric converter 3 outputs a receiver signal with a signal level corresponding to the intensity of received light. For example, a matrix array of 100 x 100 photoelectric converters is used as an image sensor 5. 3-dimensional information of the space, into which the light of the light source is being irradiated, is mapped on a 2-dimensional planar
25 surface that is a light receiving surface of the image sensor 5 through the lens 4. For example, when an object "Ob" exists in the space, a light reflected from each point of the object is received by a corresponding photoelectric converter. By detecting a phase difference between the light emitted from the light source and the light received by the

photoelectric converter, a distance between the distance measuring device and each point of the object can be determined.

The electrical output of each of the photoelectric converters 3 is input in a frequency converter 6 that functions as a sensitivity controller.

5 In this frequency converter 6, frequency conversion is performed such that the frequency of the electrical output (=receiver signal) becomes to be smaller than the emission frequency. That is, the frequency converter 6 mixes the receiver signal of the photoelectric converter with a local oscillator signal output from a clock generator 8 to generate a beat signal
10 including an envelope component corresponding to a difference between the emission frequency and the frequency of the local oscillator signal, as shown in FIG. 2. Thus, the clock generator 8 functions as a local oscillator circuit.

When there is no temporal change in the distance between the
15 measuring device and the object "Ob", the phase of the beat signal is determined according to a relationship among the phase of the light emitted from the light source 1, the phase of the local oscillator signal provided from the local oscillator circuit and the phase of the receiver signal output from the photoelectric converter 3. That is, an intensity (Y
20 1) of the receiver signal is represented by the following equation:

$$Y_1 = b_1 + a_1 \cdot \cos(\omega_1 \cdot t + \psi)$$

wherein " ω_1 " designates an angular frequency corresponding to the emission frequency, " ψ " designates a phase difference between the phase of the light emitted from the light source and the phase of the receiver signal, " a_1 " designates a constant corresponding to an
25 amplitude of the receiver signal, and " b_1 " designates a constant corresponding to dark current or outside light (temporal change is not considered). On the other hand, an intensity (Y 2) of the local oscillator signal is represented by the following equation:

$$Y_2 = b_2 + a_2 \cdot \cos(\omega_2 \cdot t)$$

wherein " ω_2 " designates an angular frequency, " a_2 " designates a constant corresponding to an amplitude of the local oscillator signal, and " b_2 " designates a constant corresponding to a direct bias.

5 Since the mixed signal of the receiver signal and the local oscillator signal is ($Y_1 \cdot Y_2$), the beat signal having the envelope component corresponding to the difference between the emission frequency and the frequency of the local oscillator signal can be obtained. The phase difference " ψ " is directly reflected in the phase of the envelope component.
10 In other words, the time corresponding to the phase difference " ψ " of the beat signal is obtained by multiplying the time corresponding to the phase difference of the receiver signal by { period of the beat signal / modulation period }.

15 When the difference between the emission frequency and the frequency of the local oscillator signal is relatively small, time corresponding to the phase difference " ψ " can be remarkably prolonged as compared with the conventional method. For example, when the emission frequency is 20 MHz, the one period is 50 ns. Therefore, according to the conventional method, data sampling of the intensity of
20 received light must be performed every short time period that is less than a quarter of 50 ns to determine the phase difference " ψ ". On the other hand, according to the present invention, when the difference between the emission frequency and the frequency of the local oscillator signal is for example 300 kHz, one period of the beat signal is approximately 3300 ns
25 ($= 1 / (3 \times 10^5)$). Therefore, the data sampling of the intensity of received light can be performed every relatively long time period less than a quarter of 3300 ns (for example, 700 ns) to determine the phase difference " ψ ".

Thus, to determine the phase difference " ψ ", the intensities of received light detected within one period of the beat signal can be used in

place of the intensities of received light detected within the modulation period of the light emitted from the light source. That is, as shown in FIG. 2, integration of the beat signal over a required integration range "Ti" are performed plural times within one period of the beat signal at the timing of a given phase interval. The phase difference " ψ " can be determined by use of the plural integrals determined within one period of the beat signal. In FIG. 2, each of the integrals (A0, A1, A2, A3) is calculated every 90 degrees of the phase interval, i.e., 0°, 90°, 180° and 270°, within one period of the beat signal. The phase difference " ψ " is obtained by substituting those integrals (A0, A1, A2, A3) into the following equation:

$$\psi = \tan^{-1} \{ (A3 - A1) / (A0 - A2) \} .$$

When the difference between the emission frequency and the local oscillator frequency is controlled to be substantially zero or extremely small, it is possible to determine the phase difference " ψ " even when generating the local oscillator signal without synchronizing with the light emitted from the light source 1. That is, as shown in FIG. 1, the beat signal output from the frequency converter 6 is input in the integrator 7. The integration is performed every quarter of period of the beat signal in synchronization with the clock signal output from the clock generator 8 to determine the integration timing and the integration range at the integrator 7. The obtained integrals of the beat signal are input in a distance operation unit 9. This operation unit 9 includes an analyzer for determining the phase difference " ψ " from the integrals provided from the integrator 7 to convert the phase difference " ψ " into the distance between the distance measuring device and the object "Ob".

In the above case, the integration is performed four times within one period of the beat signal. However, the number of times of performing the integration can be appropriately determined. In addition, in the above case, the integration is performed every quarter of period of

the beat signal. However, when the phase interval is predetermined, it is not required to adopt equally spaced phase intervals, and set the phase interval within one period of the beat signal.

As described above, since the integrals of the beat signal having a
5 frequency sufficiently lower than the emission frequency are used to determine the phase difference " ψ ", it is possible to achieve a remarkably high S/N ratio against noise components such as dark current or outside light. In addition, the detection accuracy of the phase difference " ψ " is relatively improved, as compared with the case of determining the phase
10 difference " ψ " directly from the receiver signal of the photoelectric converter. In the above case, the light emitted from the light source is intensity-modulated by the sine wave. However, the intensity-modulation may be performed by use of another waveform such as a triangular wave or a saw-tooth wave. In addition, as the light emitted from the light
15 source, infrared light or the like may be used other than the visible light. Under the influence of disturbance light such as sun light and illumination, it is preferred that an optical filter for transmitting only a wavelength of the light emitted from the light source is placed before the photoelectric converters 3. The use of this optical filter is useful too in the following
20 embodiments.

(Second Embodiment)

In the first embodiment, the photoelectric converters 3, frequency
converters 6, and the integrators 7 are independent of one another. In this embodiment, they are integrally formed as an image sensor 5. That
25 is, as shown in FIG. 3, the image sensor 5 comprises photoelectric converters 3 such as photodiodes, each of which generates, as the receiver signal, amounts of electric charges corresponding to the intensity of received light, memory cells 7a for storing the electric charges generated in the photoelectric converters 3, storage gates 6a, each of

which adjusts the amounts of electric charges migrating from the photoelectric converter 3 to the corresponding memory cell 7a, and a transfer circuit 10 that functions as a charge ejector for ejecting the electric charges stored in each of the memory cells 7a to outside

5 The storage gate 6a is switched by the local oscillator signal output from a clock generator 8, so that amounts of signal charges corresponding to a beat signal are stored in the memory cell 7a. Therefore, in this embodiment, a frequency converter 6 is composed of the storage gate 6a and the clock generator 8. In addition, since the migration amounts of
10 electric charges from the photoelectric converter 3 to the memory cell 7a as the charge storage can be adjusted by controlling the storage gate 6a by the local oscillator signal, it can be regarded that the storage gate 6a also functions as a sensitivity controller for determining a ratio of the amounts of electric charges to be supplied as the signal charges into the
15 memory cell 7a relative to the amounts of electric charges generated in the photoelectric converter 3.

As described above, the memory cell 7a stores, as the signal charges, the electric charges generated by the photoelectric converter 3 when the storage gate 6a is in the "on" state. Thus, the memory cell 7a
20 functions as the integrator 7 explained in the first embodiment. It is required to read out an output of the integrator 7 plural times within one period of the beat signal. In this embodiment, the transfer circuit 10 reads out the integral stored in each of the memory cells 7a every time period appropriately determined according to the period of the beat signal.
25 The read-out integral is then sent to an operation unit 9 as the analyzer of the first embodiment. In the operation unit 9, the phase difference " ψ " between the light emitted from the light source 1 and the light received by the photoelectric converter 3 is determined by performing the operations described in the first embodiment and a distance between the object "Ob"

and the distance measuring device is determined from the phase difference " ψ " to output an distance image.

By the way, as the photoelectric converter 3, it is possible to use a photodiode or a MOS capacitor having the capability of photoelectric conversion. On the other hand, as the memory cell 7a, it is possible to use a MOS capacitor light-shielded to prevent receiving the outside light. When a CCD is used as the MOS capacitor for the memory cell 7a, a shift gate for transferring the electric charges from the photoelectric converter 3 to the memory cell 7a can be used as the storage gate 6a. Alternatively, a MOS capacitor having the capability of separately providing electric charges may be used for the memory cell 7a. As the storage gate 6a, it is also possible to use a conventional semiconductor switch such as bipolar transistor and MOSFET. The shift gate or the semiconductor switch used as the storage gate 6a is light-shielded to prevent receiving the outside light. Alternatively, as the storage gate 6a, a MOS type device integrally formed with the photoelectric converter 3 may be used. For example, such a MOS type device comprises one having the capability of controlling the bias of a MOS capacitor and a MOS transistor. In this case, the outside light is incident on the storage gate 6a without being light-shielded. A one- or two-dimensional type image sensor may be used as the image sensor 5.

The transfer circuit 10 can be appropriately designed according to the type of the memory cell 7a used. For example, when a plurality of memory cells 7a constructs a CCD, the electric charges of each of the memory cells 7a can be read out in order by driving the CCD with readout pulse. On the other hand, in case of separately providing the electric charges from the memory cells 7a, the electric charges of each of the memory cells 7a can be read out in order by individually performing on/off operation of a MOS transistor of the semiconductor switch placed between

each of the memory cells **7a** and the operation unit **9**.

Referring to FIG. 4, the case of separately providing the electric charges from the memory cells **7a** is further explained in detail. In the present case, a 2-dimensional matrix arrangement of the photoelectric converters **3** is used. The drain of a semiconductor switch "Sv" for vertical control that is composed of a MOS transistor is connected to the memory cell **7a** corresponding to each of the photoelectric converters **3**. The gates of the semiconductor switches "Sv" corresponding to the photoelectric converters aligned in the horizontal direction are commonly connected to a horizontal signal line "Lv". The gates of the semiconductor switches "Sv" commonly connected every row of the matrix arrangement are connected to a shift resistor "SRv" for vertical control. The shift resistor "SRv" can selectively turn on the semiconductor switches "Sv" corresponding to one of the rows of the matrix arrangement. On the other hand, the source of the semiconductor switches "Sv" corresponding to the photoelectric converters **3** aligned in the vertical direction are commonly connected to a vertical signal line "Lh". The sources of the semiconductor switches "Sv" commonly connected every column of the matrix arrangement are connected to the drain of a semiconductor switch "Sh" for horizontal control that is composed of a MOS transistor. The gates of the semiconductor switches "Sh" are connected to a shift resistor "SRh" for horizontal control. The shift resistor "SRh" can selectively turn on the semiconductor switch "Sh" corresponding to one of the columns of the matrix arrangement. The source of each of the semiconductor switches "Sh" is commonly connected to an output line "Lo".

Therefore, when the semiconductor switches "Sh" aligned in the horizontal direction are turned on in order by the shift resistor "SRh" under a condition that the semiconductor switches "Sv" corresponding to one of the rows of the matrix arrangement are turned on by the shift resistor

"SRv", it is possible to provide the electric charges of each of the memory cells **7a** corresponding to the row of the matrix arrangement to the signal line. Next, when the semiconductor switches "Sh" aligned in the horizontal direction are turned on in order by the shift resistor "SRh" under
5 a condition that the semiconductor switches "Sv" corresponding to another one of the rows of the matrix arrangement are turned on by the shift resistor "SRv", it is possible to provide the electric charges of each of the memory cells **7a** corresponding to another row of the matrix arrangement to the signal line. Thus, by repeating the above procedure, it is possible
10 read out the signal charges stored in the memory cells **7a** in order. Thus, each of the shift resistors "SRh" and "SRv" functions as a controller for controlling the on/off state of the semiconductor switch "Sh" or "Sv" such that each of the memory cells **7a** is selectively connected to the output line. Other configuration and operation are similar to the first embodiment.

15 (Third Embodiment)

In this embodiment, an interline transfer CCD having a vertical-overflow drain is used as the image sensor **5**. As this type of image sensor, it is possible to use one available in the market.

As shown in FIG. 5, the image sensor **5** is a 2-dimensional image
20 sensor having a matrix arrangement of 3 x 4 photodiodes **21**. The numeral **22** designates a vertical transfer portion composed of a vertical transfer CCD provided adjacent to the photodiodes **21** of each of the columns of the matrix arrangement. The numeral **23** designates a horizontal transfer portion composed of a horizontal transfer CCD
25 provided under the vertical transfer portions. Each of the vertical transfer portions **22** has a pair of gate electrodes (**22a**, **22b**) every photodiode **21**. The horizontal transfer portion has a pair of gate electrodes (**23a**, **23b**) every vertical transfer portion **22**. The vertical transfer portion **22** is a 4-phase drive, and the horizontal transfer portion **23** is a 2-phase drive.

Therefore, the horizontal transfer portion **23** receives the signal charges every one horizontal line from the vertical transfer portions **22** and outputs the signal charges every one horizontal line. Since this type of driving technique is well known in the field of CCD, the detailed explanation is omitted.

The photodiodes **21**, the vertical transfer portions **22** and the horizontal transfer portion **23** are formed on a single substrate **20**. An overflow electrode **24** that is an aluminum electrode is directly formed on the substrate **20** not through an insulating film. That is, the substrate **20** functions as the overflow drain. The overflow electrode **24** is formed on the substrate **20** so as to surround the whole of the photodiodes **21**, the vertical transfer portions **22** and the horizontal transfer portion **23**, as shown in FIG. 5. The surface of the substrate **20** other than areas corresponding to the photodiodes **21** is covered with a light shielding film **26** (FIG. 6) described later.

Referring to FIG. 6, the image sensor **5** is more specifically explained. In the present embodiment, an n-type semiconductor substrate is used as the substrate **20**. A p-well **31** of p-type semiconductor is formed on a general surface of the substrate **20** over a region, at which the formation of the photodiode **21** and the vertical transfer portion **22** is intended, such that a thickness of the p-well at the region for the formation of the vertical transfer portion **22** is greater than the thickness of the p-well at the region for the formation of the photodiode **21**. In addition, an n⁺-type semiconductor layer **32** is formed at the region for the formation of the photodiode **21** on the p-well **31**. As a result, the p-n junction provided by the n⁺-type semiconductor layer **32** and the p-well **31** provides the photodiode **21**. A p⁺-type semiconductor surface layer **33** is formed on photodiode **21**. This surface layer **33** is known as buried photodiode.

On the other hand, a storage transfer layer **34** of n-type semiconductor is formed at the region for the formation of the vertical transfer portion **22** on the p-well **31**. The top surface of the storage transfer layer **34** is substantially flush with the top surface of the surface layer **33**, and the thickness of the storage transfer layer **34** is greater than the thickness of the surface layer **33**. A separation layer **35** of p⁺-type semiconductor having the same impurity concentration as the surface layer **33** is formed between the n⁺-type semiconductor layer **32** and the storage transfer layer **34**. The gate electrodes **22a**, **22b** are formed on the storage transfer layer **34** through an insulating film **25**. The gate electrode **22a** is insulated from the gate electrode **22b** by the insulating film **25**. As described above, the gate electrodes **22a**, **22b** are formed every photodiode **21**. One of the gate electrodes **22a**, **22b** has a larger width than the other one.

Specifically, as shown in FIG. 7, the gate electrode **22b** having the small width is configured in a planar shape, and the gate electrode **22a** having the large width is formed with a flat portion and a pair of curved portions extending from opposite ends of the flat portion. The gate electrodes **22a**, **22b** are disposed such that the curved portion of the gate electrode **22a** is partially overlapped with the gate electrode **22b** in the height direction. The top surface of the flat portion of the gate electrode **22a** is substantially flush with the top surface of the gate electrode **22b**. Therefore, the gate electrodes **22a**, **22b** are alternately disposed on the storage transfer layer over the entire length of the vertical transfer portion **22**. The insulating film **25** is made of silicon dioxide. The gate electrodes **22a**, **22b** are made of polysilicon. In addition, the surface of the image sensor **5** other than regions for allowing the photodiodes to receive the light is covered with a light-shielding film **26**.

Next, a mechanism of driving the image sensor **5** described above

is explained. When the light provided from the space is incident on the photodiode **21**, electric charges are generated by the photodiode **21**. After the electric charges generated by the photodiode **21** are supplied to the vertical transfer portion **22**, they can be stored in the vertical transfer portion **22** or transferred from the vertical transfer portion **22** by controlling voltages applied to the gate electrodes **22a**, **22b**. That is, the gate electrodes **22a**, **22b** function as the storage gate. A ratio of amounts of the electric charges supplied to the vertical transfer portion **22** relative to the amounts of the electric charges generated by the photodiode **21** changes in accordance with a depth of a potential well formed in the storage transfer layer **34** by applying the voltages to the gate electrodes **22a**, **22b** and the time period of forming the potential well. In addition, when a suitable voltage "Vs" is applied to the overflow electrode **24**, the electric charges generated by the photodiode **21** are discarded through the substrate **20**. Therefore, the ratio of amounts of the electric charges supplied to the vertical transfer portion **22** relative to the amounts of the electric charges generated by the photodiode **21** can be determined by controlling the voltage applied to the overflow electrode **24** or the time period of applying the voltage to the overflow electrode. Thus, the substrate **20** functions as an electric-charge discarding portion.

As described above, the photodiode **21** functions as the photoelectric converter, and the amounts of the electric charges supplied as the signal charge from the photodiode **21** to the vertical transfer portion **22** can be adjusted by controlling the voltage applied to at least one of the gate electrodes **22a**, **22b** and the overflow electrode **24**. Therefore, it can be regarded that at least one of the gate electrodes **22a**, **22b** and the overflow electrode **24** (i.e., the substrate **20** as the electric-charge discarding portion) functions as the sensitivity controller. In other words, when the voltage corresponding to the local oscillator signal is applied to

at least one of the gate electrodes **22a**, **22b** and the overflow electrode **24**, it can function as the sensitivity controller. In addition, the vertical transfer portion **22** can form the potential well at the region corresponding to the individual gate electrode **22a**, **22b**. Since the signal charges can be stored in the potential well, the potential well functions as the electric charge storage. Since the electric charges stored in the vertical transfer portion **22** can be output by controlling a magnitude of the voltage applied to the gate electrode **22a**, **22b**, **23a**, **23b** and timing of applying the voltage to the gate electrode, the vertical transfer portion **22** and the horizontal transfer portion function as the electric charge ejector.

For example, when controlling the voltage applied to the overflow electrode **24**, the electric charges generated by the photodiode **21** can migrate toward the vertical transfer portion **22**, as described below. That is, FIG. 8 is a schematic diagram showing a change in electron potential along the dotted-line "L1" in FIG. 6. The region designated by the numeral **21** in FIG. 8 corresponds to the photodiode. The region designated by the numeral **20** in FIG. 8 corresponds to the substrate. The region designated by the numeral **22** in FIG. 8 corresponds to the vertical transfer portion. When the voltage is not applied to the overflow electrode **24**, the potential barrier "B1" derived from the p-well **31** is formed between the photodiode **21** and the substrate **20**. In addition, when the voltages are not applied to the gate electrodes **22a**, **22b**, a potential barrier "B2" derived from the separation layer **35** is formed between the photodiode **21** and the vertical transfer portion **22**. Therefore, the height of the potential barrier "B2" can be controlled by the voltage applied to the gate electrode **22a**, **22b**. Similarly, the height of the potential barrier "B1" can be controlled by the voltage applied to the overflow electrode **24**. In FIG. 8, "e" designates electron.

By the way, it has been known from the past that when applying a

voltage to the overflow electrode **24** at an appropriate timing, it can function as an electronic shutter. When the voltage applied to the overflow electrode **24** is controlled, and a relatively high voltage is applied to the substrate **20**, the electric charges generated by the photodiode **21** can be discarded as waste charges through the substrate **20**. In other words, the amounts of electric charges supplied to the vertical transfer portion **22** can be controlled. This means that the sensitivity is adjustable.

In the present embodiment, the sensitivity is adjusted by applying the voltage corresponding to the local oscillator signal to the overflow electrode **24**, and the ratio of the amounts of electric charges supplied to the vertical transfer portion **22** relative to the amounts of electric charges generated by the photodiode **21** is modulated at the local oscillator signal. That is, frequency conversion is performed by mixing the receiver signal of the photodiode **21** (i.e., the electrical output generated by the photodiode **21**) with the local oscillator signal provided from the clock generator **8**.

In addition, since the gate electrodes **22a**, **22b** are formed on the storage transfer layer **34** through the insulating film **25**, the potential well is formed in the storage transfer layer **34** by applying the voltage to the gate electrode **22a**, **22b**, so that a capacitor for storing the electric charges can be obtained. Therefore, it is possible to perform integration within a capacity range determined by the depth and width of the potential well **27**.

FIGS. 9A to 9C show relationships between applied voltages to the gate electrode **22a** and the overflow electrode **24** and movements of the electric charges generated by the photodiode **21**. In FIG. 9A, the potential barrier "B2" derived from the separation layer **35** is removed by applying a relatively high positive voltage to the gate electrode **22a**, and the potential well **27** is formed in the storage transfer layer **34**. At this time, a relatively low voltage is applied to the overflow electrode **24** to form

the potential barrier "B1".

In this case, the electric charges generated by the photodiode **21** can not migrate to the substrate **20** by the presence of the potential barrier "B1". As a result, the electric charges can not be discarded. Therefore, all of the electric charges falling within the capacity range of the potential well **27** in the electric charges generated by the photodiode **21** migrates as the signal charges to the vertical transfer portion **22**, as shown by the arrow in FIG. 9A.

On the other hand, in FIG. 9B, a relatively high positive voltage is applied to the gate electrode **22a**, as shown in FIG. 9A, and also a relatively high positive voltage is applied to the overflow electrode **24**. The voltage applied to the overflow electrode **24** is determined such that a potential of the substrate **20** is lower than the potential of the vertical transfer portion **22**. Since the potential barrier "B1" derived from the p-well **31** is removed, a parts of the electric charges generated by the photodiode **21** can migrate as the signal charges to the vertical transfer portion **22**, and the balance of the electric charges can be discarded as waste charges through the substrate **20**, as shown by the arrow in FIG. 9B. In this case, the ratio of the signal charges relative to the electric charges generated by the photodiode **21** decreases as compared with the case of FIG. 9A. This means a reduction in the sensitivity

The sensitivity that is a ratio of the signal charges to the waster charges is determined according to magnitude relations in the voltages applied to the gate electrode **22a** and the overflow electrode **24**. Therefore, larger amounts of the electric charges (electrons) migrate toward a region of lower potential. Since the electric charges of the vertical transfer portion **22** under the condition of FIG. 9A are stored in the potential well **27**, they can not migrate to the substrate under the condition of FIG. 9B.

To read out the signal charges stored in the vertical transfer portion 22, as shown in FIG. 9C, the voltage applied to the gate electrode 22a is reduced to form the potential barrier "B2". The formation of the potential barrier "B2" prevents an inflow of the electric charges from the photodiode 21 to the vertical transfer portion 22, and an outflow of the electric charges from the vertical transfer portion 22 to the photodiode 21.

Under this condition, when 4-phase clocks "V1" ~ "V4" are provided to the gate electrodes 22a, 22b, and 2-phase clocks "VH1", "VH2" are provided to the gate electrodes 23a, 23b, it is possible to read out the signal charges stored in the vertical transfer portion 22. The signal charges stored in the vertical transfer portion 22 can be read out every determination of the respective integral (A0~A3) with respect to each of the above-described four intervals. For example, after the signal charges corresponding to the integral "A0" are stored in the potential well 27, they are read out. Next, after the signal charges corresponding to the integral "A1" are stored in the potential well 27, they are read out again. Thus, the procedure of storing and reading out the signal charges is repeated. It goes without saying that time periods of storing the integrals A0~A3 (i.e., the number of clock signals) are equally set to each other. In addition, the sequence of reading out the integrals A0~A3 is not limited to the above-described case. For example, after the integral A0 is determined, the integral A2 may be determined in place of the integral A1.

According to the present embodiment, since the voltage applied to the overflow electrode 24 is controlled, delay of response caused by capacity components is prevented as compared with the case of applying the voltages to the gate electrodes 22a, 22b formed at the vertical transfer portion 22. Therefore, it becomes possible to use a relatively high local oscillator frequency. This also means that a relatively high emission frequency can be used. As a result, it is possible to improve axial

resolution by shortening the period of intensity modulation.

In the case of controlling the vertical-overflow drain, it is possible to control the voltage applied to the p-well **31** formed on the substrate **20** in place of controlling the voltage applied to the overflow electrode **24** formed on the substrate **20**. This is ditto for another embodiments described in the present specification.

In addition, the sensitivity may be controlled by the gate electrodes **22a**, **22b** under a condition that the potential barrier "B1" has been removed by applying a high voltage to the overflow electrode **24**. That is, when there is the potential barrier "B2", the electric charges of the photodiode **21** migrate toward the overflow drain **20**. On the other hand, under the condition that the potential barrier "B2" has been removed, the electric charges of the photodiode **21** mainly migrate toward the vertical transfer portion **22**. Therefore, it is possible to control the amounts of electric charges migrating from the photodiode **21** to the vertical transfer portion **22**. Other configuration and performance are similar to the second embodiment.

(Fourth Embodiment)

A distance measuring device of this embodiment is substantially the same as that of the third embodiment other than the following features. That is, a ratio of the amounts of electric charges supplied as the signal charges to the storage transfer layer **34** relative to the amounts of electric charges generated by the photodiode **21** can be determined by controlling both of the voltages applied to the gate electrode **22a** and the overflow electrode **24**.

In FIG. 10A, a potential barrier "B2" derived from the separation layer **35** is removed by applying a relatively high positive voltage to the gate electrode **22a**, and a potential well **27** is formed in the storage transfer layer **34**. At this time, a relatively low voltage is applied to the

overflow electrode **24** to form a potential barrier "B1". In this case, the electric charges (electrons "e") generated by the photodiode **21** can not migrate to the substrate **20** by the presence of the potential barrier "B1". Therefore, waste charges do not occur. All of the electric charges falling within the capacity range of the potential well **27** in the electric charges generated by the photodiode **21** migrate as the signal charges to the vertical transfer portion **22**, as shown by the arrow in FIG. 10A.

On the other hand, in FIG. 10B, a relatively low positive voltage is applied to the gate electrode **22a**, as shown in FIG. 10A, and a relatively high positive voltage is applied to the overflow electrode **24**. The voltage applied to the overflow electrode **24** is determined such that a potential of the substrate **20** is lower than the potential of the vertical transfer portion **22**. In this case, the potential barrier "B1" derived from the p-well **31** is removed. However, since the potential barrier "B2" derived from the separation layer **35** is formed, most of electric charges generated by the photodiode **21** are discarded as the waste charges through the substrate **20**, as shown by the arrow in FIG. 10B. As a result, the ratio of the signal charges relative to the electric charges generated by the photodiode **21** decreases as compared with the case of FIG. 10A. This means a reduction in the sensitivity.

In the present embodiment, the conditions of FIGS. 10A and 10B are alternately repeated. The sensitivity that is a ratio of the signal charges to the waster charges is determined according to magnitude relations in the voltages applied to the gate electrode **22a** and the overflow electrode **24** and a ratio of the time period of applying the voltage to the gate electrode **22a** and the time period of applying the voltage to the overflow electrode **24**. Other configuration and performance are similar to the second embodiment.

(Fifth Embodiment)

In this embodiment, an interline transfer CCD having a lateral overflow drain is used as the image sensor **5**. As this type of image sensor, it is possible to use one available in the market. As shown in FIG. 11, in the image sensor **5** of this embodiment, an overflow drain **41** of n-type semiconductor is formed adjacent to each of columns of a matrix arrangement (3 x 4) of the photodiodes **21**. In this case, the image sensor **5** has three overflow drains **41**. The overflow drains **41** are connected at their upper ends to each other by an overflow electrode **24** that is an aluminum electrode. The vertical transfer portion **22** and the horizontal transfer portion **23** have the similar functions to them of the image sensor **5** of the third embodiment.

Referring to FIG. 12, the image sensor **5** is more specifically explained. In the present embodiment, a p-type semiconductor substrate is used as the substrate **40**. An n⁺-type semiconductor layer **42** is formed on a general surface of the substrate **40** over a region, at which the formation of the photodiode **21** is intended. Therefore, the photodiode **21** is composed of the n⁺-type semiconductor layer **32** and the substrate **40**. On the other hand, a storage transfer layer **44** of n-type semiconductor is formed on a general surface of the substrate **40** over a region, at which the formation of the vertical transfer portion **22** is intended.

A separation layer **45a** of p⁺-type semiconductor is formed between the n⁺-type semiconductor layer **42** and the storage transfer layer **44**. A separation layer **45b** of p⁺-type semiconductor is formed between the n⁺-type semiconductor layer **42** and the overflow drain **41**. The numeral **43** designates a p⁺-type semiconductor surface layer having the same impurity concentration as the separation layers **45a**, **45b**, which is formed on the n⁺-type semiconductor layer **42** and the separation layers **45a**, **45b**. This surface layer **43** prevents that the electric charges generated by the photodiode **21** migrate to the vertical transfer portion **22** through the

surface of the n⁺-type semiconductor layer **42**.

The top surface of the storage transfer layer **44** is substantially flush with the top surfaces of the surface layer **43** and the overflow drain **41**. In addition, a thickness of the overflow drain **41** is larger than the thickness of the n⁺-type semiconductor layer **42**. Gate electrodes **22a**, **22b** are formed every photodiode **21** on the storage transfer layer **44** through an insulating film **25**. One of the gate electrodes **22a**, **22b** has a larger width than the other one. In addition, the surface of the image sensor **5** other than areas for allowing the photodiodes **21** to receive the light is covered with a light shielding film **26**. These structures are similar to the image sensor **5** of the third embodiment.

As understood from comparisons of FIG. 13 showing a change in electron potential along the dotted line in FIG. 12 and FIGS. 14A to 14C with FIGS. 8 and 9A to 9C, the present embodiment is different from the third embodiment only in that the electric charges generated by the photodiode **21** are discarded through the overflow drain **41** in place of the substrate **20** of the third embodiment. As compared with the n⁺-type semiconductor layer **32** constructing the photodiode **21** of the interline transfer CCD having the vertical overflow drain of the third embodiment, the photodiode **21** of the interline transfer CCD having the lateral overflow drain of the present embodiment can use the n⁺-type semiconductor layer **42** having a larger thickness.

That is, in the case of forming the vertical overflow drain, it is needed to form the photodiode **21** on the substrate **20**. However, in the case of forming the lateral-overflow drain, since the substrate **40** is used as the semiconductor layer constructing the photodiode **21**, it becomes possible to increase the thickness of the n⁺-type semiconductor layer **42**. As a result, the light receiving area decreases because the overflow drain **41** is formed adjacent to the photodiode **21**. However, there is an

advantage that the sensitivity to infrared is improved as compared with the third embodiment. Other configuration and performance are similar to the third embodiment.

(Sixth Embodiment)

5 In this embodiment, a frame transfer CCD having a vertical overflow drain is used as the image sensor **5**. As this type of image sensor, it is possible to use one available in the market.

As shown in FIG. 15, the image sensor **5** of this embodiment is a 2-dimensional image sensor having a matrix (4 x 4) arrangement of
10 photodiodes **21**. This image sensor **5** is provided with an image pickup portion "D1" for allowing the photodiodes **21** aligned in the vertical direction to function as vertical transfer CCD, and a storage portion "D2" formed adjacent to the image pickup portion "D1", which is an arrangement of vertical transfer CCD not having the capability of
15 photoelectric conversion. In FIG. 15, the numeral **23** designates a horizontal transfer portion formed adjacent to the storage portion "D2", which is formed by horizontal transfer CCD. The horizontal transfer portion functions as an electric charge ejector.

In this embodiment, the photodiode **21** and the vertical transfer
20 CCD have the function of storing electric charges and transferring the electric charges in the vertical direction. Therefore, the image pickup portion "D1" and the storage portion "D2" function as the electric charge storage. Each of the columns of the matrix arrangement of the image pickup portion "D1" has four photodiodes **21**, each of which is formed at
25 the light receiving surface with three gate electrodes **21a~21c** aligned in the vertical direction. Each of the columns of the vertical transfer CCD in the storage portion "D2" has two sets of three gate electrodes **28a~28c**. In addition, as in the case of the third embodiment, the horizontal transfer portion **23** has a pair of gate electrodes **23a, 23b** every column of the

storage portion "D2".

The gate electrodes **21a~21c** are driven by a 6-phase clock "V1" ~"V6", and the gate electrodes **28a~28c** are driven by a 3-phase clock "VV1"~"VV3". The gate electrodes **23a, 23b** are driven by a 2-phase clock "VH1", "VH2". The horizontal transfer portion **23** outputs the signal charges from the storage portion "D2" every one horizontal line. Since this type of driving technique is well known in the field of CCD, the detailed explanation is omitted.

The image pickup portion "D1", the storage portion "D2" and the horizontal transfer portion **23** are formed on a single substrate **50**. An overflow electrode **24** that is an aluminum electrode is formed directly on the substrate **50** not through an insulating film. That is, the substrate **50** functions as an overflow drain. The overflow drain electrode **24** is formed on the substrate **50** so as to surround the whole of the image pickup portion "D1", the storage portion "D2" and the horizontal transfer portion **23**. The surface of the substrate **50** other than areas corresponding to the photodiodes **21** is covered with a light shielding film (not shown).

Referring to FIG. 16, the image sensor **5** is more specifically explained. In the present embodiment, an n-type semiconductor substrate is used as the substrate **50**. A p-type semiconductor layer **51** is formed on a general surface of the substrate **50** over a region, at which the formation of the photodiode **21** is intended. In addition, an n-well **52** of n-type semiconductor is formed in the p-type semiconductor layer **51**. The p-n junction provided by the p-type semiconductor layer **51** and the n-well **52** provides the photodiode **21**. In addition, as shown in FIG. 16, the three gate electrodes **21a~21c** are formed on top surfaces of the p-type semiconductor layer **51** and the n-well **52** through an insulating film **53** of silicon dioxide. Each of the gate electrodes **21a~21c** is made of polysilicon.

The n-well **52** is continuously formed over the image pickup portion "D1" and the storage portion "D2". That is, in the n-well **52** of the image pickup portion "D1" the electric charges are generated, stored and transferred, and in the n-well **52** of the storage portion "D2", the electric charges are stored and transferred.

Next, a mechanism of driving the image sensor **5** described above is explained. When the light provided from the space is incident on the photodiode **21**, electric charges are generated by the photodiode **21**. When suitable voltages are applied to the gate electrodes **21a~21c**, a potential well is formed as the electric charge storage in the n-well **52**. The generated electric charges can be stored in the potential well. In addition, since the depth of the potential well can be changed by controlling the voltages applied to the gate electrodes **21a~21c**, it is possible to transfer the electric charges by controlling the depth of the potential well. That is, the gate electrodes **21a~21c** function as the storage gates.

On the other hand, when a suitable voltage "Vs" is applied to the overflow electrode **24**, the electric charges generated by the photodiode **21** are discarded through the substrate **50**. Therefore, by controlling the voltage applied to the overflow electrode **24** and a time period of applying the voltage to the overflow electrode **24**, it is possible to change a ratio of amounts of the electric charges stored as the signal charges in the potential well of the n-well **52** relative to the amounts of the electric charges generated by the photodiode **21**. That is, by applying the voltage corresponding to the local oscillator signal to the overflow electrode **24** (i.e., the substrate **50**), the ratio of the signal charges relative to the electric charges generated by the photodiode **21** can be controlled. Therefore, as in the case of the third embodiment, the substrate **50** functions as the sensitivity controller.

Referring to FIG. 17 showing an electron potential along the dotted line in FIG. 16, the migration of electric charges generated by the photodiode **21** is explained. The region designated by the numeral **21** in FIG. 17 corresponds to the photodiode. The region designated by the numeral **50** in FIG. 17 corresponds to the substrate. When no voltage is applied to the overflow electrode **24**, a potential barrier "B3" derived from the p-type semiconductor layer **51** is formed between the photodiode **21** (n-well **52**) and the substrate **50**. On the other hand, at the side opposed to the substrate **50** of the photodiode **21**, a potential barrier "B4" derived from the p-type semiconductor layer **51** is formed.

By the formation of these potential barriers, it is possible to prevent the leakage of electric charges (electrons "e") generated by the photodiode **21** to the outside. The height of the potential barrier "B3" can be determined by controlling the applied voltage to the overflow electrode **24**. On the other hand, amounts of electric charges stored in the potential well formed by applying the voltages to the gate electrodes **21a** ~ **21c** are determined by the depth of the potential well, which is determined by the applied voltages to the gate electrodes **21a** ~ **21c**. That is, when the voltage applied to the gate electrode **21b** is higher than the voltages applied to the gate electrodes **21a**, **21c**, the potential well is formed to have the maximum depth at its center region, as shown in FIG. 18.

When a suitable voltage is applied to the overflow electrode **24** such that the potential of the substrate **50** is lower than the potential of the n-well **52**, voltages are applied to the gate electrodes **21a**, **21c** to remove the potential barrier "B3", and a voltage is applied to the gate electrode **21b** to form the potential barrier "B3", large amounts of electric charges (electrons "e") are stored at the center region, as shown in FIG. 19B, and the electric charges are discarded at the both side regions through the

substrate **50**, as shown in FIGS. 19A and 19C. Thus, it is possible to adjust the ratio of the signal charges stored in the potential well formed in the n-well **52** relative to the electric charges generated by the photodiode **21** by giving the local oscillator signal to the overflow electrode **24**. That is, since the sensitivity is controlled by the local oscillator signal, the amounts of signal charges stored in the potential well become the amounts of electric charges corresponding to the integrals $A0 \sim A3$ of a beat signal at the time defined by the 6-phase clock "V1"~"V6".

By the way, a part of electric charges generated at the side gate electrodes **21a**, **21c** flow into the potential well corresponding to the center gate electrode **21b** as noise components during a time period over which the electric charges are generated by the photodiode **21**. In addition, since the signal charges are transferred every determination of the respective integral $A0 \sim A3$, the electric charges generated by the photodiode **21** are mixed in the integral $A0 \sim A3$ as the noise components during the time period of transferring the signal charges. However, these noise components are averaged by integration, and substantially removed by subtraction performed to determine the phase difference " ψ ". Therefore, the influence of those noise components becomes small. That is, it is possible to accurately determine the phase difference " ψ " even though the frame transfer CCD is used.

In addition, since an aperture ratio of the photodiode **21** can be increased by use of the frame transfer CCD, it is possible to achieve a higher sensitivity as compared with the case of using the interline CCD. In the above case, the three gate electrodes **21a**~**21c** are provided every photodiode **21**. However, the number of gate electrodes corresponding to one photodiode is not limited to this embodiment. Other configuration and performance are similar to the third embodiment.

(Seventh Embodiment)

In this embodiment, a frame transfer CCD having a lateral overflow drain is used as the image sensor **5**. As shown in FIG. 20, the image sensor **5** of this embodiment is a 2-dimensional image sensor having a matrix (4 x 4) arrangement of photodiodes **21**. An overflow drain **61** of n-type semiconductor is formed adjacent to each of columns of the matrix arrangement of the photodiodes **21**. In this case, the image sensor **5** has four overflow drains **61**. The overflow drains **61** are connected at their upper ends to each other by an overflow electrode **24** that is an aluminum electrode. The image pickup portion "D1", the storage portion "D2" and the horizontal transfer portion **23** have the similar functions to them of the image sensor **5** of the sixth embodiment.

Referring to FIG. 21, the image sensor **5** is more specifically explained. In the present embodiment, a p-type semiconductor substrate is used as the substrate **60**. A p-type semiconductor layer **62** is formed on a general surface of the substrate **60**. In addition, an n-well **63** of n-type semiconductor is formed in the p-type semiconductor layer **62**. The p-type semiconductor layer **62** and the n-well **63** provide the photodiode **21**. A p⁺-well **64** of p⁺-type semiconductor is formed adjacent to the n-well **63** in the p-type semiconductor layer **62**. The overflow drain **61** of n-type semiconductor is formed in a top surface of the p⁺-well **64**. Thus, the image sensor **5** of this embodiment has basically same structure as the image sensor of the sixth embodiment except for using the substrate **60** having a different conductivity type and forming the overflow drain **61**. However, there is an advantage that the image sensor of this embodiment has a higher sensitivity to infrared, as compared with the sixth embodiment.

As understood from the comparison of FIG. 22 showing a change in electron potential along the dotted line L4 of FIG. 21 with FIG. 17, the present embodiment is different from the sixth embodiment in that the

electric charges generated by the photodiode **21** are discarded through the overflow drain **61** in place of the substrate **50** of the sixth embodiment. Amounts of electric charges stored in a potential well formed in the n-well **63** by applying voltages to gate electrodes **21a~21c** are determined by the depth of the potential well, which is determined by the applied voltages to the gate electrodes **21a~21c**. That is, when the voltage applied to the gate electrode **21b** is higher than the voltages applied to the gate electrodes **21a, 21c**, the potential well corresponding to the center gate electrode **21b** has the maximum depth.

When a suitable voltage is applied to the overflow electrode **24** to lower the potential barrier "B3", electric charges (electrons "e") are stored at the potential well corresponding to the center gate electrode **21b**, as shown in FIG. 23B, and electric charges generated at the regions corresponding to the side gate electrodes **21a, 21c** are discarded through the overflow drain **61**, as shown in FIGS. 23A and 23C. Other configuration and performance are similar to the sixth embodiment.

(Eighth Embodiment)

As explained in the sixth and seventh embodiments, when using the frame transfer CCD as the image sensor **5**, the number of gate electrodes formed every photodiode **21** is not limited to three. In this embodiment, four gate electrodes are formed every photodiode **21**.

In FIGS. 24A and 24B, the numerals **1~4** respectively designate first, second, third and fourth gate electrodes. One cycle period of the numerals **1~4** corresponds to a region of one photodiode **21**. FIG. 24A shows a period of storing electric charges generated by the photodiode **21**, and FIG. 24B shows a period of discarding unnecessary charges. A threshold value "Th1" designates a potential of overflow drain.

As shown in FIG. 24A, in the period of storing the electric charges, a potential barrier is formed between adjacent photodiodes **21** by not

applying a voltage to the first gate electrode (1) in order to prevent that that electric charges generated by each of the photodiodes 21 are mixed to each other. In addition, when voltages applied to the second, third and the fourth gate electrodes (2)~(4) are reduced in a stepwise manner, it is possible to obtain step-like potential wells having different depths. Each of regions corresponding to the third and fourth gate electrodes (3), (4) has a potential higher than the threshold value "Th1". At a region corresponding to the second gate electrode (2), the potential well has the maximum depth (the lowest potential). Since this potential is lower than the threshold value "Th1", electric charges (electrons "e") generated by the photodiode 21 are mainly stored in the region corresponding to the second gate electrode (2).

On the other hand, as shown in FIG. 24B, in the period of discarding the electric charges, potentials of the regions corresponding to the third and fourth gate electrodes (3), (4) are increased to prevent leakage of electric charges stored in the region corresponding to the second gate electrode (2) that has the lowest potential in the period of storing the electric charges. Thereby, electric charges generated at the regions corresponding to the first, third and the fourth gate electrodes (1), (3), (4) in the period of storing the electric charges flow into the overflow drain and the region corresponding to the second gate electrode (2). Therefore, it is possible to adjust a ratio of amounts of waste charges relative to the amounts of electric charges generated by the photodiode 21 by appropriately controlling a ratio of the period of storing the electric charges to the period of discarding the electric charges. This means that the sensitivity is adjustable. Other configuration and performance are similar to the sixth or seventh embodiment.

(Ninth Embodiment)

In this embodiment, six gate electrodes are formed every

photodiode **21**. In FIGS. 25A and 25B, the numerals **1~6** respectively designate first, second, third, fourth, fifth and sixth gate electrodes. One cycle period of the numerals **1~6** corresponds to a region of one photodiode **21**. FIG. 25A shows a period of storing electric charges generated by the photodiode **21**, and FIG. 25B shows a period of discarding unnecessary charges. A threshold value "Th2" designates a potential of overflow drain.

As shown in FIG. 25A, in the period of storing the electric charges, a potential barrier is formed between adjacent photodiodes **21** by not applying a voltage to the first gate electrode (**1**) in order to prevent that that electric charges generated by each of the photodiodes **21** are mixed to each other. At a region corresponding to the fourth gate electrode (**4**), the potential well has the maximum depth. Potentials of regions corresponding to the second, third, fifth and the sixth gate electrodes (**2**), (**3**), (**5**), (**6**) are increased in a stepwise manner so as to be higher than the threshold value "Th2". As described above, at the region corresponding to the fourth gate electrode (**4**), since the potential well has the maximum depth, which is lower than the threshold value "Th2", electric charges (electrons "e") generated by the photodiode **21** are mainly stored in the region corresponding to the fourth gate electrode (**4**).

As shown in FIG. 25B, in the period of discarding the electric charges, potentials of the regions corresponding to the second, third, fifth and sixth gate electrodes (**2**), (**3**), (**5**), (**6**) are increased to prevent leakage of electric charges stored in the region corresponding to the fourth gate electrode (**4**) that has the lowest potential in the period of storing the electric charges. Thereby, electric charges generated at the regions corresponding to the first, second, third, fifth and sixth gate electrodes (**1**), (**2**), (**3**), (**5**), (**6**) in the period of storing the electric charges flow into the overflow drain and the region corresponding to the fourth gate electrode

(4).

Therefore, as in the case of the eighth embodiment, it is possible to adjust a ratio of amounts of waste charges relative to the amounts of electric charges generated by the photodiode 21 by appropriately controlling a ratio of the period of storing the electric charges to the period of discarding the electric charges. This means that the sensitivity is adjustable. Other configuration and performance are similar to the sixth or seventh embodiment.

(Tenth Embodiment)

As described above, when using the frame transfer CCD as the image sensor 5, electric charges generated by the photodiode 21 in a time period other than the periods of determining the integrals A0~A3 may be mixed as the noise components into the signal charges. The noise components are substantially constant, and averaged by storing the electric charges within the periods of determining the integrals A0~A3. Therefore, it is possible to remove the noise components to some extent and determine the phase difference " ψ ".

However, the S/N ratio reduces due to the noise components. For example, when a larger dynamic range is needed at regions relating to storing or transferring of the electric charges, the cost/performance of the distance measuring device deteriorates. In the present embodiment, as shown in FIGS. 26A and 26B, a light-shielding film 65 is formed on the region of storing signal charges, and the region not relating to the generation of electric charges of the photodiode 21.

In FIGS. 26A and 26B, as in the case of the ninth embodiment, six gate electrodes (1) to (6) are formed every photodiode 21. Specifically, the light-shielding film 65 is formed at the regions corresponding to the gate electrodes (1), (3)~(5), so that electric charges (electrons "e") are generated only at the regions corresponding to the gate electrodes (2), (6)

of the photodiode **21**. As a result, the gate electrode (**4**) does not substantially contribute the generation of electric charges. In other words, the noise components do not occur at the gate electrode (**4**). As compared with the case of not forming the light-shielding film **65**, it is possible to improve the S/N ratio. Other configuration and performance are similar to the ninth embodiment.

In the above-explained embodiments, electric charges are output every determination of the respective integral $A_0 \sim A_3$. An image sensor **5** explained below has the capability of simultaneously determining at least two of the integrals $A_0 \sim A_3$.

(Eleventh Embodiment)

In this embodiment, a modification of the frame transfer CCD shown in FIG. 20 is used as the image sensor **5**. That is, as shown in FIG. 27, overflow drains (**61a**, **61b**) are alternately disposed such that each of the overflow drains is provided every photodiode **21**. Therefore, it is needless to say that electric charges generated by each of the photodiodes **21** can be separately discarded.

A ratio of amounts of signal charges migrated to the potential well of an electric charge storage relative to the amounts of electric charges generated by the photodiode **21** can be adjusted by giving a local oscillator signal to each of the overflow drains **61a**, **61b**. In this embodiment, local oscillator signals " $\phi 1$ ", " $\phi 2$ " are given to adjacent overflow drains **61a**, **61b** in the direction of transferring the signal charges at the same frequency but in opposite phase. By use of the local oscillator signals " $\phi 1$ ", " $\phi 2$ " having the same frequency but in the opposite phase, beat signals respectively corresponding to the local oscillator signals are also in opposite phase, as shown in FIGS. 28A and 28B.

That is, when the above-described control is performed under a condition that one pixel is provided by a set of adjacent two photodiodes

21, electric charges corresponding to each of the beat signals in the opposite phase are stored in the electric charge storage corresponding to each of the two photodiodes 21. By performing integration with respect to each of these beat signals in opposite phase, it is possible to simultaneously obtain two of the four integrals $A_0 \sim A_3$ required to determine the phase difference " ψ ". That is, in this embodiment, both of the integrals A_0 , A_1 can be simultaneously stored, and both of the integrals A_2 , A_4 can be simultaneously stored.

In this embodiment, since the signal charges are mixed with extraneous electric charges with an intended purpose, they become noise components. However, amounts of the extraneous electric charges are much smaller than the signal charges, and the extraneous electric charges are mixed at a substantially constant ratio with the signal charges. Therefore, the noise components have a minimal influence on determining the phase difference " ψ ". Other configuration and performance are similar to the seventh embodiment.

(Twelfth Embodiment)

In the eleventh embodiment, a modification of the interline transfer CCD having the lateral overflow drain may be used as the image sensor 5 in place of the modification of the frame transfer CCD. That is, as shown in FIG. 29, overflow drains (41a, 41b) are alternately disposed adjacent to the photodiodes 21 aligned in the vertical direction such that each of the overflow drains is provided every photodiode 21. In addition, three gate electrodes 22a~22c are formed every photodiode 21 in a vertical transfer portion 22.

In this image sensor 5, one pixel is provided by a pair of adjacent photodiodes 21 in the vertical direction, and local oscillator signals " $\phi 1$ ", " $\phi 2$ " are given to overflow drains 41a, 41b corresponding to the two photodiodes 21 defining the pixel at the same frequency but in opposite

phase. In addition, as in the case of the eleventh embodiment, the gate electrodes **21a~21c** are driven by a 6-phase clock. As a result, it is possible to simultaneously determine two of the integrals $A_0 \sim A_3$. Other configuration and performance are similar to the eleventh embodiment.

5 In the eleventh and twelfth embodiments, three gate electrodes are formed every overflow drain. However, the number of gate electrodes formed every overflow drain may be four or more. In addition, when four local oscillator signals having phases which are different from each other by 90 degrees are given to different overflow drains in place of the local
10 oscillator signals " $\phi 1$ ", " $\phi 2$ " in opposite phase, it is possible to simultaneously determine the integrals $A_0 \sim A_3$. Moreover, the local oscillator signals " $\phi 1$ ", " $\phi 2$ " in opposite phase may be given to the gate electrodes **21a~21c**, **22a~22c**. Alternatively, the local oscillator signals " $\phi 1$ ", " $\phi 2$ " in opposite phase may be given to both of the overflow drain
15 and those gate electrodes.

In the above embodiments, the interline transfer CCD or the frame transfer CCD are used as the image sensor **5**. In addition, as shown in FIG. 30, it is possible to use a frame interline transfer CCD, which is obtained by replacing the image pickup portion "D1" of the frame transfer
20 CCD of FIG. 15 with the photodiodes **21** and the vertical transfer portions **22** of the interline transfer CCD. In this case, there is an advantage that the occurrence of smear can be prevented, as compared with the frame transfer CCD.

In the above-explained embodiments, a 1-dimensional image
25 sensor may be used in place of the 2-dimensional image sensor. In addition, only one photoelectric converter **3** may be used in the first embodiment. In addition, the analyzer for determining the distance information is used in the above embodiments. However, as the information about the intended space, only the phase difference " ψ " may

be determined by the analyzer. Alternatively, another information about the intended space are evaluated or determined by the analyzer according to the integrals $A_0 \sim A_3$.

5 INDUSTRIAL APPLICABILITY

As described above, according to the spatial information detecting device of the present invention, even when a distortion of the waveform of the light received by the photoelectric converter occurs due to a distortion of the signal waveform for driving the light source or a temporal change in the amount of light incoming from outside into the space, there is little influence on measuring accuracy because the integration of the beat signal is used to determine the spatial information. Therefore, there is an advantage that the spatial information can be detected with improved accuracy, as compared with conventional detecting devices that the measuring accuracy is influenced by the waveform. In addition, since the spatial information is determined by use of the integration of the beat signal having a lower frequency than the emission frequency of the intensity-modulated light, there is another advantage that a relatively cheap switching device is available at the light receiving side in place of an expensive switching device having high-speed response.

The spatial information detecting device having these advantages of the present invention is widely available to any devices required to determine the phase difference between the intensity-modulated light and the received light, and particularly suitable to the distance measuring device.